Trigonometric method used to correct local coordinates topographic surveys, applied for archaeology

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Abstract: Trigonometric method used to correct local coordinates topographic surveys, applied for archaeology. The necessity of Stereo 70 topographical surveys for archaeological sites raises the issue of access to coordinates needed to create a proper measurement aligned to the Romanian national system. In most situations involving our team, Stereo 70 coordinates of sites that had to be measured were unknown or the site itself was still unknown, being unidentified yet, and thereby we were forced to use local coordinates for those particular surveys. Local coordinates involve an orientation issue, orientation mainly achieved with the help of a compass to indicate the magnetic North, thus implying another issue: the difference between true (geographic) North and magnetic North. In our experience the difference between our survey and the reality was between 7 and 12 trigonometric degrees. The software methods used rotations based on the shapefiles thus leaving the source coordinates unaltered, but these created inconveniences because both shapefiles and source coordinates, among other digital data, must be handed over to the Ministry of Culture and Cults in order to obtain the excavation authorization. Also, the archaeologists who requested the surveys need geographically correct data. This trigonometric method involves trigonometric correction of the raw data acquired by the total station and its conversion to Stereo 70, thus offering precise data and surveys to researchers and institutions.

Key words: Stereo 70, survey, archaeological topography, coordinates, orientation, Romania.

Introduction

In the actual context of Romanian archaeology, in order to acquire authorizations for systematic archaeological research, the following digital data are required: topographic survey plan in Stereo 70 projection in digital format (ArcMap shapefiles), a plan presenting ancient and modern landmarks and the overlaying on orthophotomap with the size of 2,5 x 2,5 km. These data were sent to the Ministry of Culture and Cults and to the Institute for Cultural Memory (cIMeC).

The current legislation requires: the topographic survey of the site using Stereo 70 coordinate in .dwg or .shp format and the orthophotomap (1:5000) in digital format containing the georeferenced file for the area of the site[1]. Also for preventive research, archaeological diagnosis and archaeological surveillance these data are required[2].

Also, according to the Order of the Ministry of Culture OMC 2408/2005 states the National eGISpat Program to elaborate a digital map of historic monuments in GIS needed to protect the national immobile cultural heritage – historic and archaeological monuments (eGISpat 2012).

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[1] Monitorul Oficial 768/2010, Art. 10

[2] Monitorul Oficial 768/2010, Art. 11, Art. 12, Art. 13

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The Stereographic projection on Secant unique plan 1970, or Stereo 70, was adopted for the Romanian territory in 1973 and it is still in use. It is based on the elements of Krasovski-1940 ellipsoid and it uses the elevation reference plan Black Sea-1975 (B. Moroşanu 2007; D. Micle *et al.* 2011, p. 56; M. Breazu *et al.* 2003, p. 415; A. Năstase, G. Osaci-Costache 2005, p. 147).

In order to start a topographic survey we need the following: site location, site surface, site landmarks, landmarks coordinates in Stereo 70, orientation, elevation, equipment and trained specialists. For some sites we were unable to obtain the field coordinates that are obligatory for a correct survey, such as: landmarks coordinate, orientation and elevation. The elevation issue is relatively simple to solve in the laboratory by using topographical maps.

But our greatest challenge consisted of dealing with Stereo 70 coordinates and orientation, because we found ourselves in the middle of the field with no coordinates to set up our total station and with no orientation landmarks, thus we were forced to conduct the topographical survey using local coordinates, such as 5000 x 5000 meters for North and East fields and compass orientation towards the magnetic North.

When imported, edited and overlaid onto the satellite image or othophotomap our measurements were rotated in trigonometric direction with an angle between 7 and 12 degrees, implying incorrect orientation issues, given by the difference between the magnetic and the real North. Our colleagues from the Geography Department and surveyors of the company that provided the equipment offered a solution that involved editing and rotation of points measured within the shape file based on our measurements that eventually lead to a correct overlay, but did not alter the source coordinates of measured points. We needed a solution to adjust the source of the points, the coordinates, in order to have a correct set of coordinates that would overlay the othophotomap with a precise orientation, thus creating an accurate plan.

The solution was given by trigonometry. With the help of Monica Dăgădiţă, a Computer Science engineer from the University of Bucharest, we managed to use and apply a rotation formula and a methodology that proved to be precise and time saving for our future surveys. This formula can be applied in MS Excel to the coordinates thus applying the rotation angle needed and a new set of precise and correct coordinates will be obtained. The rotation trigonometric formula is known as a part of Euclidean transformations (J. Smart 1994; 1998).

Formula
The formula requires concomitant transformations for the x and y columns because is based on both values in the same time.

The formulas for x' and y', the new rotated values for x and y, are:

$$x' = x*\cos(\alpha*\Pi / 180) - y*\sin(\alpha*\Pi / 180)$$
$$y' = x*\sin(\alpha*\Pi / 180) - y*\cos(\alpha*\Pi / 180)$$

Above, α represents the angle needed for the rotation, x and y represent the initial values of the point coordinates, x' and y' represent the new values of the point coordinates and Π represents the mathematical pi value.

If our survey needs a trigonometric direction rotation then the angle value must be positive and if we need a reverse trigonometric direction rotation, the angle value must be negative (J. Smart 1994; 1998).

Methodology
There are a number of steps required for this transformation to be successful, such as: identification of landmarks coordinates within the orthophotomap and within the local coordinates measurements, establishing the elevation, local coordinates conversion in order to position the station point into the centre of the Cartesian system (x and y coordinates become 0), angle determination, rotation formula, Stereo 70 coordinates conversion for landmarks, overlaying, coordinates control and export.

Step 1: first of all we determine the elevation based on topographic maps for one of the points within our measurement. In MS Excel we will apply add or subtract formula to get all points to the real elevation. If the local coordinates point has a 102 meters elevation and the same point has a real elevation of 186 meters, we will add 84 meters to all points in order to apply correct height information. The total station has already given height difference between points when measured starting from its setup.

Step 2: identification of landmarks coordinates within the orthophotomap and within the local coordinates measurements is done after importing both data into ArcMap and identifying common landmarks: roads, rivers, railways, intersections in general and especially poles, ancient or modern buildings corners and antennas. Now we have a common set of coordinates for landmarks and we know what calculus we have to apply to determine the Stereo 70 location of the points. The total stations use the following coordinate system: X for Northing, Y for Easting and Z for elevation.

For example: the measured point named Pole1 has the local coordinates (142, 58, 186) and the Stereo 70 coordinates are (280342, 444658, 186).

Step 3: using MS Excel we will add to all points on the x column the value 280200 and to all point on the y column the value 444600 in order to position the measurement to that particular area and to overlay them to the othophotomap. These values are obtained by subtracting the local values from the real values. For the moment, the only point that will be precise will be Pole1, the other points still having an orientation issue (fig. 1).

This point, Pole1, will become our Stereo 70 main landmark; it will be used to transform all points to Stereo 70 and to check our orientation angle correction.

Step 4: to determine the orientation angle difference we can use vector graphics software, such as CorelDraw. We can import the image of the points overlaid onto the orthophotomap in Step 3 and draw two lines based in point Pole1, one for the local survey and one for the image and determine the angle between them. In our experience, the angle difference between the compass obtained magnetic North and the real North fits between 7 and 12 degrees.

Step 5: to be able to apply the rotation formula we have to set the centre of the survey into the centre of the Cartesian system. The centre of the survey represents the station point that has the values inserted when setting up the station. Being a local coordinate's survey we can use any values that can fit the surveyed points. We generally use 5000 x 5000 meters, meaning

that the station point has the coordinates (5000, 5000, 100) where we could not access Stereo 70 coordinates. The elevation value was already modified during Step 1, but the formula deals only with x and y fields, elevation remains unchanged – as measured and then corrected.

To position the station point into the 0, 0 coordinates for x and y we have to subtract for both columns in MS Excel their value for all points, in order to keep the ratio. For our case, we will subtract the value 5000 for both columns, x and y, and the station point will become (0, 0, elevation).

Step 6: having the station point based in the centre of the Cartesian system, we can now proceed to applying the formula on both x and y columns in the same time. It is obligatory to respect this concomitant calculus because the new values, x' and y', will have to be pasted as values over x and y columns in the same time in order not to alter ratio and correctness.

Our points are now rotated to the determined angle, but are still positioned in the center of the Cartesian system, as the (0, 0, elevation) coordinates of the station point remain unaltered.

Step 6: using the Pole1 point Stereo 70 coordinates, established as main landmark in Step 3, we will set our survey into the Stereo 70 system. Using MS Excel we will add to the x and y values of Pole1 the value needed to become (280342, 444658), determined in Step 2. These values will be added to the whole x and y columns in order to obtain the Stereo 70 coordinates and to preserve ratio.

Step 7: the new, rotated and converted, set of data will be overlaid onto the othophotomap to verify the angle and the level of correctness of the measurement.

This methodology was developed in time based on our team's survey experience with the available software and instruments. The training for instruments and software usage was initially done with the help of the Geography Department and the company that provided the survey equipment. This rotation formula was successfully used for most of our local coordinates surveys, summing up to around 150 survey sessions.
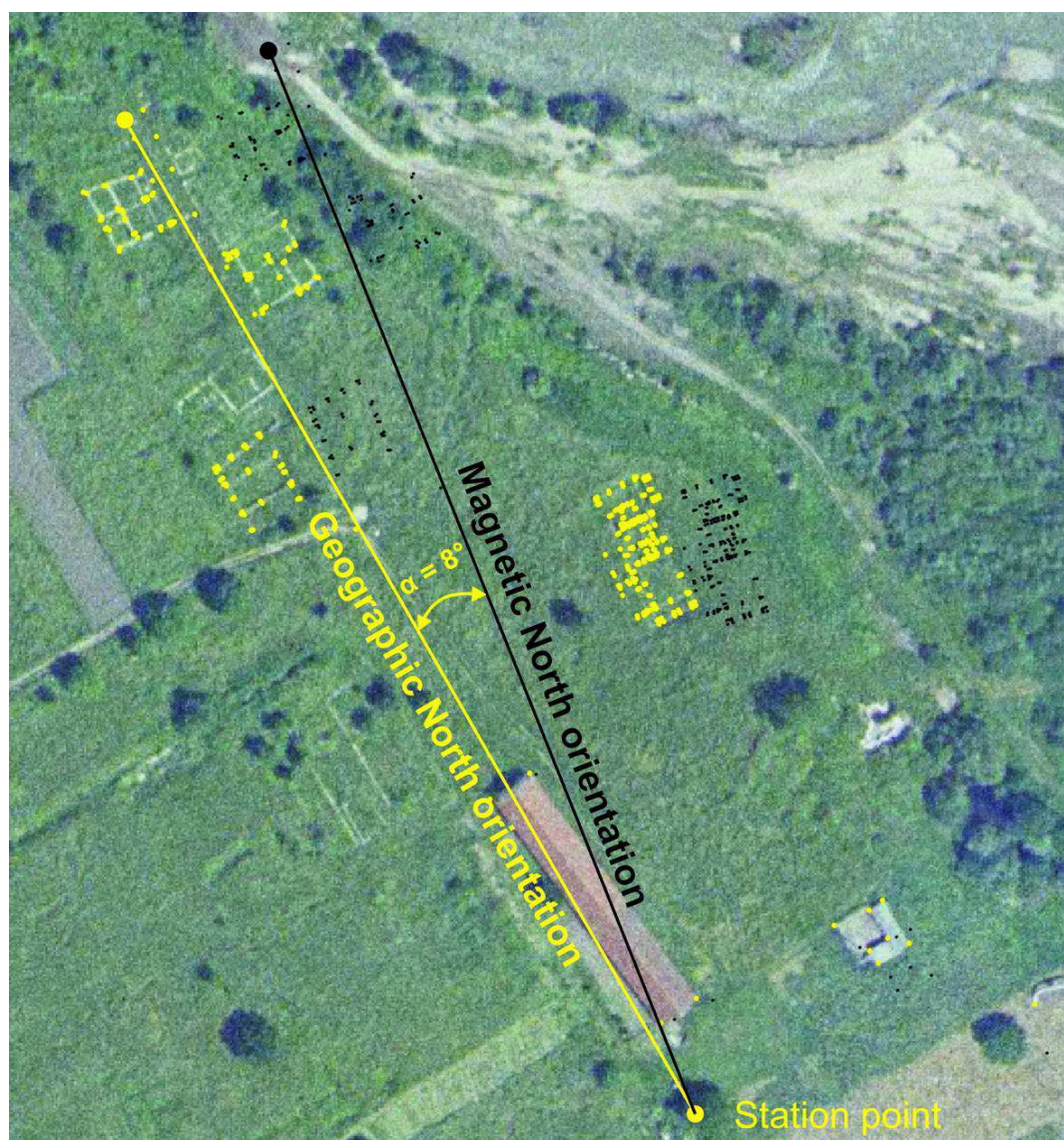
Fig. 1 **-** Image representing in black the survey oriented using a compass and in yellow the corrected survey, based in the same station point, with a rotation angle α = 8°. The site is *Tibiscvm* – Jupa (Caraș Severin County) and the survey represents modern landmarks and ancient buildings measured initially using local coordinates and a compass for orientation, afterwards corrected using our formula.

Conclusion

After following these steps, we obtained a correct overlay of genuine correct survey data onto the othophotomap by altering the values of the coordinates obtained from the total station and thus, we are able to create and edit a precise and qualitative plan to be used by professionals and institutions. We did not rotate a shape file to obtain a good looking plan without correct background coordinates, but we set up the initial values of the local coordinates into rotated, Stereo 70 values and by such we offered complete digital data of the survey which can be used and overlaid onto any other map or satellite image.

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